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TRANSLATION OF

TEMPERATURE RELATION OF THE MAGNETOSTRICTION OF SATURATION OF IRON SILICIDE MONOCRYSTALS

('Temperaturnaia zavisimost' magnitostriktsii nasyshcheniia monokristallov kremnistogo zheleza')

by

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THE TEMPERATURE RELATION OF THE MAGNETOSTRICTION OF SATURATION OF IRON SILICIDE MONOCRYSTALS

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The magnetostriction constants of iron silicide monocrystals (3.5% Si) for the axes [100] [110] and [111] in plane (110) and their change in the temperature interval from -196 to 800° C are determined. The domain structure of the investigated samples are also examined.

INTRODUCTION

A study of the temperature relation of magnetostriction is quite valuable for the theory of ferromagnetism and for a whole number of problems involved with the utilization of ferromagnetic substances. The magnetostriction constants λ_{100} and λ_{111} which are the basis of the magnetization theory, enter into formulas [1]; therefore it is extremely essential to know the temperature relation of these constants for a complete understanding of the nature of technical magnetization. Much work [2-7] has been devoted to experimental determination of the magnetostriction constants of the monocrystals of various ferromagnetics. Heaps [2] and Takaki [8, 9] determined the magnetostriction constants in monocrystalline samples to facilitate the use of ferromagnetic substances (iron silicide) in technology; Carr and Smolychowski [10] investigated the relationship between λ_{100} and λ_{111} and the silicon concentration. However, only one work by D. A. Shturkin [11] has been written on the investigation of the temperature relation of the magnetostriction constants of iron silicide monocrystals; the temperature relation of λ_{100} in the temperature range from 20° to 600° C was studied experimentally in this work. The magnitudes λ_{110} and λ_{111} were not found experimentally but rather from the familiar Akulov law of anisotropy [1]. As was indicated by Shturkin [11] λ_{100} in the given temperature range is positive and increases with an increase in temperature reaching a maximum at 480° C, after which it begins to decrease. The constant λ_{111}, being negative, only decreases in absolute value with a temperature increase. Magnetostriction of saturation in the direction [110] at all magnetization values remains positive throughout the entire given temperature range.

It should be noted that the investigated temperature range was inadequate since it did not encompass the regions of low temperatures and did not make it possible to trace the change in the magnetostriction constants close to the Curie points.

The fact that no consideration of the initial state of the sample by observing the initial domain structure was given in any of the enumerated works is one of their general inadequacies.

This work first investigates the temperature dependence of magnetostriction on a monocrystalline sample of iron silicide (3.5% silicon) for all main axes in the rather wide temperature interval from -196 to 800° C with a simultaneous study of the initial domain structure.

METHODOLOGY OF THE EXPERIMENT AND THE INVESTIGATED SAMPLES

Magnetostriction was measured in the instrument described in [12] using attached and remote transducers. Such a combined use of transducers made it possible to a sufficient extent, to utilize their positive quantities for application to the problems of this work. At relatively low temperatures, attached transducers were required, and remote transducers in the temperature ranges close to the Curie point, since the former cannot be used in the given case. The arrangement made it possible to fix the magnetostriction with a $\pm\ 0.15 \cdot 10^{-6}$ error. The maximum magnetic fields were 3600 ergs.

The entire complex of the investigations was made on monocrystalline samples in the form of strips 50 x 4 x 0.3 mm in size, which were obtained by the "etching method" from sheets of transformed steel (3.5% silicon), consisting of rather large crystals, whereupon only those whose surface coincided with the crystallographic plane

(110) were used. The samples - strips were etched along the main directions of the axes [100], [110], [111]. The crystallographic orientation of the samples was determined by X-rays according to the Laue method. After careful, mechanical and then electrolytic buffing for maximum decrease of the remaining internal axes, the samples were tempered in a high vacuum at 1000° C for 20 hours. After slow cooling in a furnace, the domain structure was examined and then the magnetostriction was measured.

RESULTS OF THE EXPERIMENT AND A DISCUSSION OF THEM

Examination of powder photos in a tempered sample etched along the axis [100] indicated, as should be expected, that they are plane-parallel lamellar (domains), located along the given axis (figure 1).

Figure 1. Powder photos of (the domains) in a tempered monocrystalline sample of iron silicide (plane (110), axes [100]). Enlarged 100 times.

As is known the sample is magnetized along the axis [100] due to the 180 degree shifts of the vectors of the r naining magnetization of the domains which should not cause deformation of the sample, and therefore the magnetostriction in the given case, should be equal to zero. However, multiple measurements established the presence of negligible magnetostriction (I in figure 2), which can be explained by two reasons: first, by the presence in the sample of negligible remaining internal directions, which were not eliminated by most careful tempering and are not apparent when examining the domain structure, and second by the possibility of reconstructing the domain structure within the sample when passing from one of its surfaces to another. The latter was established experimentally by Kirenskii and Savchenko [13], who showed that in actual ferromagnetic crystals, the domain structure, as a rule, is not plane-parallel lamellae, penetrating the crystal throughout.

The effect of short-term, weak, elastic deformations on the sample does not cause changes in the initial domain structure (figure 1). Mea while, the magnitude of the magnetostriction in this case undergoes n t eable changes (II in figure 2). Obviously, these deformations pr d change in the internal energy.

Curve III in fi e 2 determines the magnetostriction of the same monocrystal. a of a slightly plastically deformed sample. Magnetostriction in this case increases even more. Moreover, the initially plane-parallel domains are reconstructed, and a part disappear completely (figure 3). This reconstruction depends on the value and direction of the acting stresses.

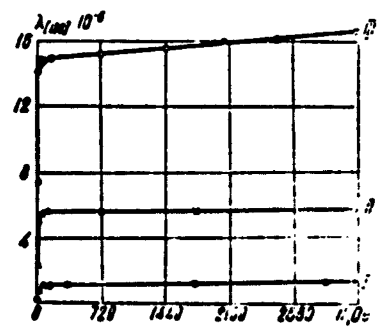

Figure 2. Magnetostriction of an iron silicide monocrystal along the axis [100] of plane [110]. Sample: I - tempered, II - elastically deformed, III - plastically deformed.

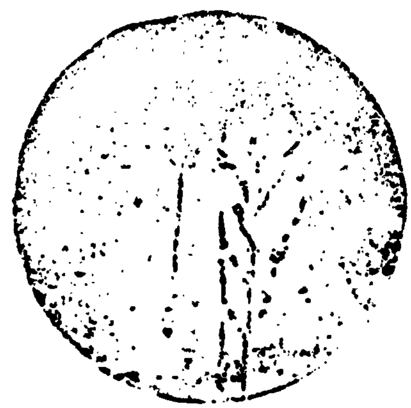

Figure 3. Powder photos of the domains in a tempered, slightly plastically deformed iron silicide monocrystal (plane (110), axis [100]), enlarged 100 times.

From what has been said, it follows that all the data on magnetostriction obtained by various authors should be referred to carefully, since in this case it is necessary to take the initial state of the investigated samples into account as well as the plane of the crystal in which the magnetostriction was determined. The latter is verified quite graphically by comparing the results of this work with the results in [11]. In the first case λ_{100} of the tempered sample, cut out in plane (110) is $1.2 \cdot 10^{-6}$ and in the second, for the same sample but cut out in plane (100), it is $24 \cdot 10^{-6}$. This difference should be expected, since the two axes of light magnetization located at a right angle relative to each other, are in plane (100). When the sample is demagnetized, the magnetization vectors of the domains are located equiprobably along these axes. When an external magnetic field is superposed along one of these axes, the sample will be magnetized by 180 degree as well as 90 degree shifts which also determine the quite significant magnetostriction of the sample. The data of the argument can be applied to other crystallographic directions.

Figure 4 gives the results of research of the temperature relation of the magnetostriction of saturation for three crystallographic directions in plane (110). The data of this work are indicated by the solid lines, and Shturkin's data by the dashed lines [11]. Magnetostriction of saturation along the axis [100] with an increase in temperature first decreases and reaches a minimum approximately close to 20° C. Then it increases, reaching a maximum at 480° C, after which it decreases to zero at the Curie point. The considerable quantitative divergence of the values of $\lambda_{s\,100}$ (t) from the data in [11] have already been explained above. It is impossible to explain such behavior in the curve of $\lambda_{s\,100}$ (T) from the point of view of the classical theory [1], which requires a linear decrease in λ_s with an increase in temperature.

Quantum-mechanics computations of the temperature relation of magnetostriction [14] indicated the complex nature of this relation and the possibility of an increase in λ_s with temperature, which has been verified quantitatively by the results of the research in [11] and the present work.

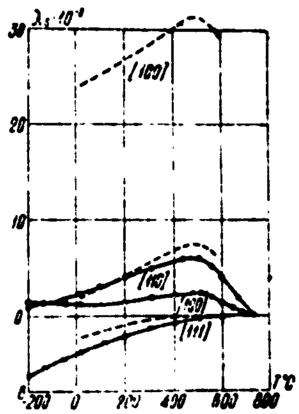

Figure 4. Temperature relation of the magnetostriction of saturation of an iron silicide monocrystal for the main axes of plane (110). Solid lines, data in this work; dashed lines, Shturkin's data [11].

In direction [110] the magnetostriction of saturation with an increase in temperature first increases and after reaching a maximum at 480° C, decreases to zero where it reaches the Curie point.

The magnetostriction of saturation along axes [100] and [110] is always a positive value for the entire investigated range of temperatures, with all values of magnetization. In the direction [111], on the other hand, it has only negative values in all temperature ranges and with an increase in temperature smoothly decrease in absolute value, reaching the zero value at 600° C.

A comparison of the obtained data with the data in [11] shows their quite good agreement.

The magnetostriction constants at room temperature (20° C) have the following values:

$$\lambda_{[100]} = +1.2 \cdot 10^{-6}; \qquad \lambda_{[110]} = +2.3 \cdot 10^{-6};$$

$$\lambda_{[111]} = -3.9 \cdot 10^{-6}.$$

CONCLUSIONS

1. The magnetostriction constants $\lambda_{[100]}$ $\lambda_{[110]}$ and $\lambda_{[111]}$ are not universal for monocrystals. To a considerable extent, they depend on the examined plane of the crystal.

2. In the study of magnetostriction, it is always necessary to take the magnetic structure of the sample into account and to remember that even negligible short-term deformations can have a great effect on the value and behavior of magnetostriction.

3. The magnetostriction of saturation of an iron silicide monocrystals along axis [100] in plane (110), when there are not any deforming forces and during the conditions of an "open" domain structure should equal zero, as follows from the theory.

4. The temperature relation of the magnetostriction of saturation along the main crystallographic axes does not agree with present classical theories.

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